EOS Validation Annual Report for Year 2002

Global Validation of EOS-AQUA Land Surface Dynamics Using Data Assimilation

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Summary of the Report

The primary goal of this NASA EOS validation project titled "Global Validation of EOS-AQUA Land Surface Dynamics Using Data Assimilation" is to develop a data assimilation technology to validate the land products generated from the AMSR_E instrument on board the EOS AQUA satellite. These land products include: surface soil moisture, brightness temperatures, surface temperature, and vegetation water content. During the first year (2002) of this project, an Extended Kalman Filter (EKF) data assimilation algorithm is implemented in NASA's Land Data Assimilation System (LDAS) using the MOSAIC land surface model. Before real and reliable AMSR-E land surface soil moisture data become available, the EKF-LDAS is successfully tested with data derived from the Tropical Rainfall Measurement Mission (TRMM) Microwave Imager (TMI). Results from EKF-LDAS are presented to American Geophysical Union Spring and Fall Meetings and AMSR_E Science and Validation meeting. A journal paper to describe the data assimilation technique for AMSR_E land product validation is in preparation. As a team effort, the SMEX02 field experiment was carried out in central Iowa for more than three weeks. We have participated the field data collection and analysis. These field data sets together with new field data sets to be collected in Okalahoma in the summer of year 2003 will be used to cross validate the AMSR-E soil moisture products. Starting from year 2003, near real time and newly calibrated AMSR_E data are progressively collected at our computing facilities. The brightness temperatures, soil moisture, surface temperature data of AMSR_E will be assimilated into the LDAS to generate more reliable data products of soil moisture and surface temperature. After a cross validation with field measurements from SMEX02 and SMEX03 these corrected AMSR_E data products will be submitted to the National Snow and Ice Data Center in Boulder, CO for archive. More tasks are planned to carry out in year 2003.

Objectives of the Project

Provision of high quality remotely-sensed global land surface measurements is a key element of NASA's Earth Science Enterprise Program. However, it is recognized that these data fields will contain uncertainties due to imperfect instrument calibration and inversion algorithms, geophysical noise, representativeness error, communication breakdowns, and other sources. It is therefore essential that the accuracy and credibility of these remotely-sensed fields be evaluated for their use in critical research and applications.

Data assimilation systems have been used extensively in meteorology to expose significant defects in satellite data processing schemes, technology limits, bias, and noise. Modern data assimilation techniques use relevant prior data and a state-of-the-art computer model to estimate the state of the land surface. For each observation, a background value is derived from the model forecast for comparison. Systematic differences between observations and model predictions can identify systematic error, or identify uncharacteristically large differences in observations. Thus the consistency of the model provides guidance to identify observation problems in a data assimilation context.

As one of the AQUA validation efforts, this project titled as "Global Validation of EOS-AQUA Land Surface Dynamics Using Data Assimilation" is to determine the nature and variability of uncertainties in selected global soil moisture and snow products, measured by the EOS-AQUA AMSR-E sensor on a variety of time scales, and to analyze the effects of these uncertainties on the predictability of the global surface water and energy balance using land surface data assimilation techniques in near real-time. Specifically, we have the following objectives, or tasks:

1) *Soil moisture and snow observation quality monitoring*: We will use innovative land surface data assimilation techniques to check the quality control, physical consistency, and systematic realism of global EOS-AQUA land observations, in the context of the collaborative, real-time Land Data Assimilation System (LDAS) project. The goal will be to develop a nearly real-time operational land data assimilation system that will monitor the spatial-temporal AMSR soil moisture and snow observation quality, so as to provide feedback to mission operators of observational problems.

2) *Production of land surface soil moisture and snow water observation fields using data assimilation*: This system will extend AMSR-E products in time and space to produce consistent data assimilation land surface fields that will be valuable for use in subsequent analysis and application.

3) *Cross validation with in situ and airborne observations*: Selected *in situ* and airborne land surface observations will be used as a secondary test of data integrity. The innovative validation strategies will feed back to improve the calibration and accuracy of EOS land-surface observations. These improvements will lead to enhanced characterization of the spatial and temporal dynamics of

uncertainty in these critical land surface quantities and will benefit climate and weather prediction efforts.

In the following sections, we will report project progress and accomplishments, future work plan, data management and archive strategy on each of these three objectives respectively.

Task 1: Soil moisture and snow observation quality monitoring

1.1. Progress and Accomplishments:

Data assimilation techniques generate a superior estimate of a system state by merging its observation and model simulation. Before assimilating the observations into model simulations, the quality of the observations should be examined. For the AMSR-E land product validation using data assimilation, the following checks are developed for the observation quality monitoring:

(a) *Theory or realism checks:* Is the observation absolute value or time change physically realistic?
(b) *Buddy checks:* Is the observation comparable with nearby (space & time) observations?
(c) *Background checks:* Is the observation changing similarly to the model prediction?
(d) *QC statistics:* Provide maps and regional statistics of QC decisions.

In year 2002, AMSR_E data were not calibrated well enough for quantitative use. Besides the selection of the above quality checks, no other significant actions were carried out under this task.

1.2. Work Plan for Next Year:

AMSR_E brightness temperature data calibrated with the newly improved calibration algorithm become available to AMSR_E science and validation teams in February 2003. However, the brightness temperatures of the 6.9GHz are severely contaminated with Radio Frequency Interfering (RFI). The land products currently available to the science and validation team members are based on the 6.9GHz brightness temperatures and are thus not yet useful. The Algorithms of AMSR_E land products will be modified. They will use the data of the non-contaminated channels. After land products based on the modified algorithms become available from the science team members, we will generate a computer code to implement the above quality checks. This task will produce quality checked land observations and QC statistics for the data assimilation of the next task.

1.3. Data Management and Archive:

This task will produce Quality Checked AMSR_E land products and QC statistics. These intermediate land products will be stored in house and analyzed in Task 2 for further validation with data assimilation. The QC statistics will be used in the data assimilation algorithm. Task 2 output will be cross-validated in Task 3. Then the final product from Task 3 will be submitted to the National Snow and Ice Center for archive.

Task 2: Production of land surface soil moisture and snow water observation fields using data assimilation

2.1. Progress and Accomplishments:

This task is to use data assimilation to evaluate and assess error in the observations after finishing the Quality Check in Task 1. This involves the following subtasks:

(2.1) develop a data assimilation algorithm for assimilating the AMSR_E land products into land surface model;

(2.2) implement the algorithm in NASA's Land Data Assimilation System (LDAS) for operational execution of assimilating the AMSR_E land products;

(2.3) Compare the observations with the assimilation output to determine and correct any bias of the observations.

For Task 2.1, the Extended Kalman Filter (EKF) data assimilation method is selected for assimilating surface soil moisture observations into the MOSAIC model. The EKF is a statistical assimilation technique that updates the soil moisture profile based on the relative magnitudes of the co-variances of the observations and the model profile estimates. The main advantage of EKF is that the entire profile may be updated because of the correlation between the surface soil moisture and the soil moisture of deeper soil. The algorithm tracks the conditional mean of a statistically optimal estimate of a state vector **X** through a series of forecast and update steps.

For Task 2.2, the EKF is implemented in NASA's Land Data Assimilation System (LDAS) by adding a series of Fortran 90 subroutines or functions into the LDAS code. The EKF-LDAS code is then tested with two sets of surface soil moisture data for the 140km by 280km SGP99 study area: one is a synthetic data set obtained from the assumed a perfect "MOSAIC" model and the other is the retrieval from the Tropical Rainfall Measurement Mission (TRMM) Microwave Imager (TMI). With these two data sets, a series of numerical experiments were carried out to test the efficiency of the EKF data assimilation method. Results of these experiments are presented gradually to several science meetings (see the following Publication and Presentation List). A summary of these results is provided in Figures 1-4 attached to the end of this report.

Publication and presentation list:

Zhan, X., J.K. Entin, P.R. Houser, J.P. Walker and R.H. Reichle. Application of Kalman Filtering for soil moisture data validation with NASA's Land Data Assimilation System. EOS: Transaction of American Geophysical Union, 83(19): S194, Spring Meet. Suppl. Abstract H51D-09, 2002.

Zhan, X. & P. R. Houser. Soil moisture data assimilation using Kalman Filter and NASA's Land Data Assimilation System. NASA's AMSR-E Science and Validation Team Meeting, Santa Rosa, CA. September, 2002

Zhan, X., P.R. Houser, J.K. Entin, J.P. Walker and R.H. Reichle. Estimation of Model Error Covariance Matrices of the Extended Kalman Filter for Validation of AMSR-E Soil Moisture Product. Accepted to the Fall Meeting of American Geophysical Union. San Francisco, December 6-10, 2002.

Zhan, X., P.R. Houser, J.K. Entin, J.P. Walker and R.H. Reichle. 2002. Implementation of the Extended Kalman Filter in NASA's Land Data Assimilation System for soil moisture data assimilation. In preparation for *Journal of Hydrometeorology*.

For Task 2.3, no actions were carried out because AMSR_E soil moisture and snow observations were not generated yet.

2.2. Work Plan for Next Year:

For Task 2.1, an Ensemble Kalman Filter (EnKF) will be implemented in LDAS for both soil moisture and snow observation data assimilation. A comparison between EKF-LDAS and EnKF-LDAS will be conducted to examine the advantages of these data assimilation methods.

For Task 2.2, a time series of soil moisture retrieval data from TMI will be generated by a USDA group. The data set will be assimilated into EKF_LDAS and EnKF_LDAS to generate a model corrected TMI surface soil moisture data product. Experience with TMI soil moisture data assimilation will be use to carry out the validation

For Task 2.3, data assimilation results from Task 2.2 will be compared with observations to identify biases of observations. Simple methods will be developed to correct the biases.

2.3. Data Management and Archive:

Data assimilation output from Task 2 will be stored in house. After further validation with in situ and airborne observations, the data assimilation results will be submitted to the National Snow and Ice Data Center (NSIDC) for archive. A data submission form has been sent to the NSIDC for a place holder for our assimilated AMSR-E land data products.

Task 3: Cross validation with in situ and airborne observations

3.1. Progress and Accomplishments:

As a team effort, the SMEX02 field experiment was successfully carried out in central Iowa for more than three weeks. We have participated the field data collection and analysis. Collected data include: gravimetric and theta probe soil moisture, vegetation height, leaf area index, wet and dry weight of leaves and stems for more than 20 watershed sites, soil samples and theta probe soil moisture for more than 50 regional sites, and airborne remote sensing of soil moisture, fluxes of the Iowa region for more than three weeks. A SMEX02 workshop was held to summarize the data collected and results obtained from data analysis. More information about SMEX02 can be obtained at http://hydrolab.arsusda.gov/smex02/

3.2. Work Plan for Next Year:

A field experiment called SMEX03 will be conducted in several sites in the US and on site in Brazil in the summer of 2002. We have planned to participate the field work.

A website for archiving intermediate and final assimilated AMSR_E land products will be created. Documents of the project and the data products will be presented in this website.

3.3. Data Management and Archive:

Data assimilation results from Task 2 will be cross validated with in situ and airborne observations. Output will be submitted to NSIDC for archive.

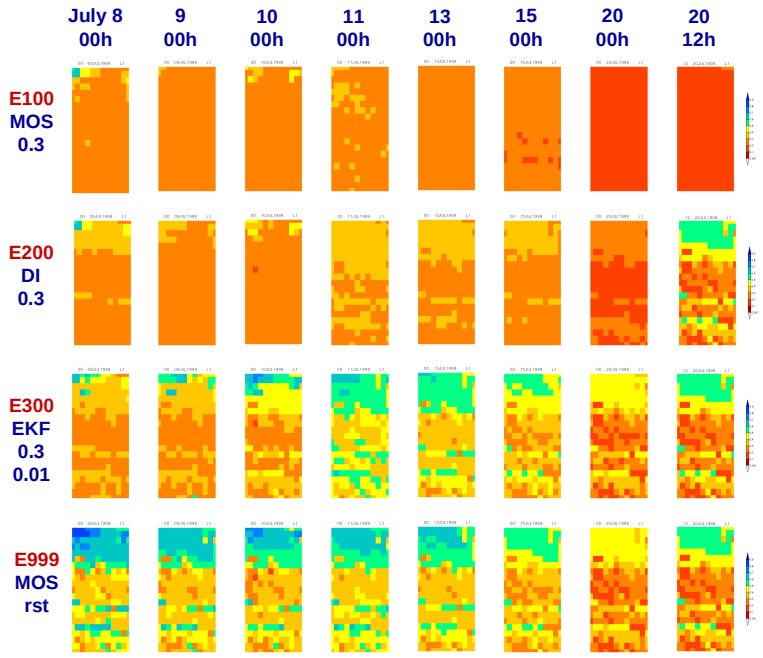

Figure 1. Result 1 of the numerical experiments with EKF-LDAS: Comparison between Extended Kalman Filter (EKF) and Direct Insertion (DI) data assimilation methods. EKF is shown to be superior to DI in term of data assimilation efficiency.

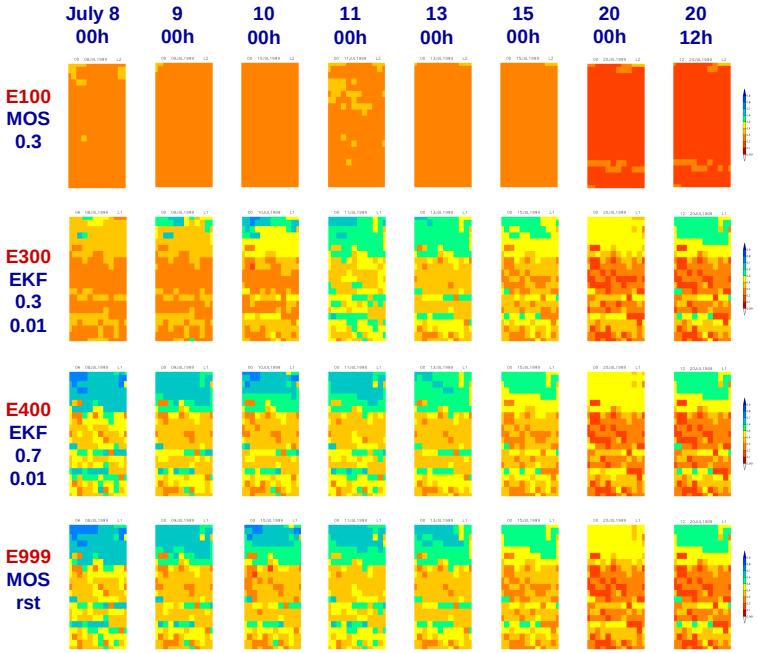

Figure 2. Result 2 of the numerical experiments with EKF-LDAS: Impact of initial soil moisture value on the efficiency of EKF data assimilation. When the initial soil moisture is high (0.7 * field capacity), the EKF assimilated soil moisture field becomes close to the "truth" after one assimilation comparing to the more than three assimilations for the dry (0.3 * field capacity) initial soil moisture case.

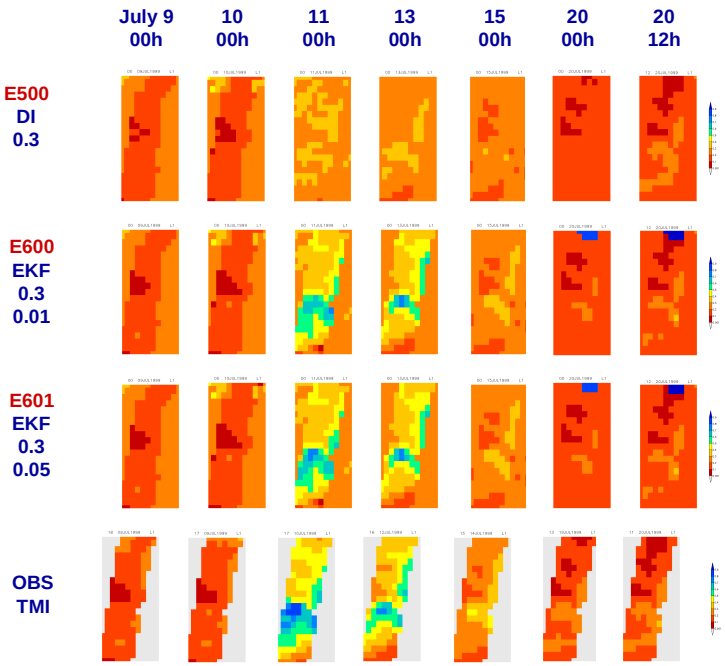

Figure 3. Result 3 of the numerical experiments with EKF-LDAS: Impact of model error covariance setup. When the observation error variance is small (0.005*field capacity) comparing to model error covariance, whether model error covariance is high (0.05fc) or low (0.01fc) does not make significant difference to the assimilation results.